

Development of An Efficient Communication System using VLC and Li-Fi

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Abstract— In this study, we propose a cost-effective solution for vehicle-to-vehicle (V2V) communication by utilizing readily available Light Emitting Diodes (LEDs) and solar panels to implement Visible Light Communication (VLC). VLC serves as an efficient and economical medium to interface with Intelligent Transport Systems (ITS), particularly for road safety applications. By leveraging the tail lamps of vehicles as transmitters, data signals can be relayed to trailing vehicles, enabling timely safety measures to mitigate potential collisions. A simplified yet robust and secure prototype for a V2V communication system has been developed. Furthermore, we introduce a method for secure and efficient data exchange, termed Secure Light Communication, which harnesses the inherent directionality of VLC to ensure that only intended target vehicles participate in the communication, enhancing security and reliability.

Index Terms—Accelerometer, Communication, Fractionated Cipherng, Light Emitting Diode (LED), Morse Code, Vehicle-to-Vehicle (V2V), Visible Light Communication (VLC)

I. INTRODUCTION

VLC-based V2V communication utilizes visible light spectrum for wireless information transmission between vehicles. It has the potential to revolutionize road safety and traffic efficiency by enabling vehicles to exchange critical information about positions, velocities, and intentions. This allows for proactive collision avoidance and cooperative maneuvers, leading to reduced accidents and improved traffic flow.

In a typical VLC-based V2V setup, a transmitter encodes messages using Morse Code and encrypts them with a standard algorithm. The encoded and encrypted message is modulated onto the visible light signal emitted by a light-emitting diode (LED) transmitter. The receiver uses a photodetector to convert the received light signals into electrical signals, decrypts and decodes the message, and retrieves the original information.

The benefits of VLC-based V2V communication include real-time communication, quick response times, and enhanced traffic flow. Vehicles can exchange information about positions, velocities, and intentions, enabling proactive measures to avoid accidents and improve overall transportation efficiency.

However, clear channels are essential for effective VLC-based V2V communication, as obstacles and noise can cause signal attenuation and interference. Additionally, VLC relies on line-of-sight communication and may face challenges in scenarios with high ambient light.

To address these challenges, a novel system for V2V communication using VLC is proposed. This system utilizes off-the-shelf LEDs and photodiodes, enabling cost-effective integration with intelligent transport systems (ITS) for road safety applications. The Directionality property of VLC is employed to establish communication links exclusively with intended target vehicles, minimizing communication overhead.

The system emphasizes the importance of security in V2V communication and proposes a secure light communication protocol. Messages transmitted via VLC can be encoded using Morse Code and encrypted to ensure confidentiality. Decryption at the receiver end allows the extraction of relevant information.

The prototype V2V system aims to transmit emergency hard brake messages from a leading vehicle to following vehicles. By receiving these messages, following vehicles can take appropriate actions to avoid accidents. The system combines directionality, off-the-shelf components, and a secure light communication protocol to provide an effective and cost-efficient solution for V2V communication.

In summary, VLC-based V2V communication has the potential to enhance road safety and traffic efficiency by leveraging visible light spectrum for wireless information transmission between vehicles. The proposed system integrates off-the-shelf LEDs and photodiodes, utilizes directionality, and incorporates a secure light communication protocol. By transmitting emergency messages and ensuring targeted communication, the system aims to improve road safety and facilitate timely responses to potential accidents.

II. METHODOLOGY

A. Vehicle to Vehicle Communication:

The proposed system consists of two interconnected vehicles: a transmitter and a receiver. The transmitter vehicle is equipped with an array of sensors, including an ultrasonic sensor, an accelerometer, and a touch sensor, all interfaced with an Arduino Uno microcontroller. These sensors capture real-time data such as speed, acceleration, orientation, and braking status. The microcontroller processes this data and directs the H-Bridge Motor Driver to execute the necessary control actions. Simultaneously, the processed data is transmitted using a Li-Fi transmitter operating at a baud rate of 2400. To provide operational transparency, an LCD panel displays the status and key parameters of the transmitter vehicle. The receiver vehicle is equipped with a microcontroller connected to a Li-Fi receiver and an H-Bridge Motor Driver. The Li-Fi receiver, with a solar panel acting as the reception boundary, captures the transmitted data. This data is processed by the Arduino Uno microcontroller, which compares it against predefined parameters to determine appropriate safety actions, such as emergency braking or speed reduction. An LCD panel displays the receiver vehicle's status and provides a visual representation of the decrypted and decoded secure message received from the transmitter.

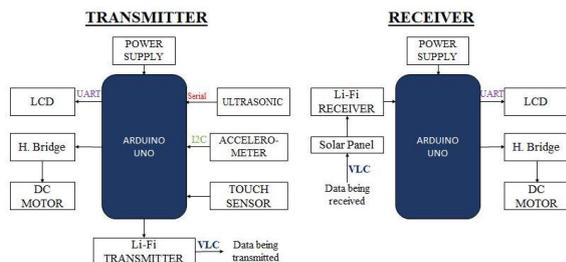


Figure 1: Block Diagram of the proposed system

This system efficiently leverages Li-Fi technology for high-speed data transmission and real-time

vehicle-to-vehicle communication. Its robust integration of sensors and microcontrollers ensures accurate data analysis and prompt responses, promoting enhanced safety and reliability in intelligent transport systems.

The system utilizes visible light communication (VLC) by encoding the sensor data into binary values and transmitting them through blinking light signals. The solar panel captures the transmitted information, and the receiver takes actions based on the threshold values set for each sensor.

a. Transmitter Vehicle

In the transmitter section, a regulated Pulse Width Modulation (PWM) circuit is implemented using a 555 timer to generate precise control signals. These signals are fed into a MOSFET driver circuit, where the MOSFET functions as a switch to regulate the LED driver circuit. The LED driver amplifies and increases the input signal frequency, optimizing it for efficient transmission.

Additionally, a three-axis accelerometer/gyroscope detects the vehicle's tilt angles. The analog data from the accelerometer is digitized via Arduino's Analog-to-Digital Converter (ADC). A safety threshold of 0.3g along the z-axis and y-axis is defined to monitor orientation and activate the braking system if exceeded.

Name of the Sensor	Threshold Values
Ultrasonic Sensor	15 cm
Accelerometer	0.3*g (g = 9.8m/s ²)
Hard Brake	1011
Soft Brake	1101

Table 1: Threshold Values being set for various sensors

The above table depicts the threshold values set for the sensors, which are used to trigger the actions in the receiver vehicle. Necessary actions are triggered in the subsequent vehicle, autonomously.

b. Receiver Vehicle

In the receiver part, a solar panel is used to receive the incoming light carrying the data. Different codes are received based on the distance to an obstacle or hard braking. The Arduino triggers actions accordingly, including displaying messages and stopping the vehicle.

The system enables secure messaging by encoding and encrypting text messages, ensuring data security

Fractionated Morse key allows us to quickly identify the key that corresponds to it without ever having to verify that the purported plain text actually decodes correctly. The plan is to begin with a random key and then alternate them continuously.

Overall, this vehicle-to-vehicle communication system incorporates VLC, sensor data analysis, secure messaging, and appropriate action triggering to enhance road safety and communication between vehicles.

III. RESULTS AND DISCUSSIONS

The following were the results of the transmitter part in its first iteration.

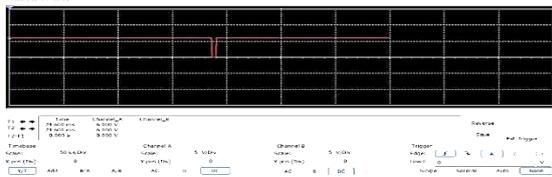


Figure 5: Multisim simulation of transmitter part showing PWM wave

The inference from the above result is that the PWM circuit built for the LED Driver Circuit in the transmitter part is working properly and is giving the required output at the required rate of 13.4 Hz which is well within the baud rate range of 2400.



Figure 6: Serial Monitor Window in Arduino IDE depicting the Morse Code for the given text and its encrypted form

The inference from the above result is that when the morse code implementation of the secret messaging system was done, a suitable encryption method had to be found which was easier to implement and efficient in the same manner. After much research and survey, Fractional Ciphering was chosen which worked best with Morse. After each letter is converted to Morse, 'X' is added between the code of each letter for easier differentiation and 'XX' is added after each word. Then the whole data set is grouped into 3 sets called triads and each triad is assigned with a unique character corresponding to its ASCII code.

Then the construction of the transmitter part was carried out and the overall transmitter system was checked for its output, whether all the sensors are

interfaced correctly with the microcontroller and if the data is being collected from them.

Next the transmitter and receiver modules were mounted on separate vehicles and the whole system was tested mimicking the original scenario.

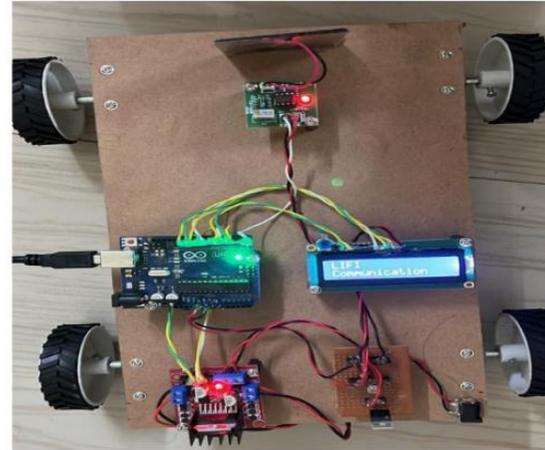


Figure 7: LCD panel at transmitter

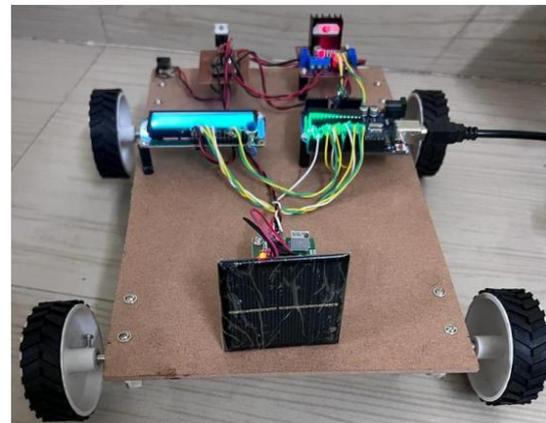


Figure 8: LCD panel at receiver

The following are the results obtained.

Sensor	Threshold	Message Displayed
Ultrasonic Sensor (HC-SR04)	< 15 cm	“Soft Brake Applied, Stopping Vehicle”
Accelerometer (MPU6050)	< 0.3g (g = 9.8m/s ²)	“Vehicle Fell”
Hard Brake (Touch Sensor)	Enable = 1	“Hard Brake Applied, Stopping Vehicle”

Table 2: Results Scenario of the Sensors

- i. The transmitting LED light and the receiving solar panel must be in Line-of-Sight condition to efficiently collect data.
- ii. The transmitter is capable of transferring data at 2400 baud rate.

- iii. Anything other than the specified baud rate, produces an undesirable garbage value.
- iv. When the distance between the obstacle and transmitter vehicle is less than the threshold, it slows down and a message is received by the receiver vehicle which states that 'Soft Brake Applied Stopping Vehicle'.



Figure 9: Soft brake scenario

- v. If the touch sensor of the transmitter vehicle is activated, which is mimicking the sudden braking scenario in real life, a message is received by the receiver stating, 'Hard Brake Applied Stopping Vehicle' and both the vehicles stop automatically.



Figure 10: Hard brake scenario

- vi. If the transmitter vehicle undergoes a change in its angle from its mean position, it mimics the scenario where the vehicle is tilted due to collision, a message is received by the receiver stating, 'Vehicle Fell Stopping Vehicle' and both the vehicles stop automatically.



Figure 11: MPU 6050 output

The further process in the system implementation was to incorporate the security messaging feature into this. As discussed earlier, Fractionated Morse Ciphering was used as the encryption technique. For the observation purposes two messages, 'hi' and 'how are you' were transmitted from the transmitter vehicle.



Figure 10: Upon reception of data

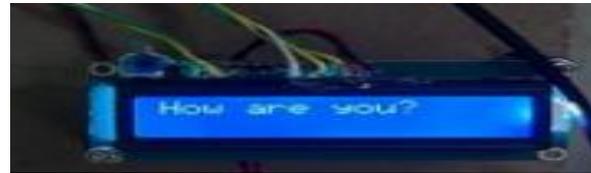


Figure 10: Decrypted data at the receiver

IV. CONCLUSION AND RECOMMENDATIONS

This paper investigates the practical application of Visible Light Communication (VLC) in a Vehicle-to-Vehicle (V2V) scenario within Intelligent Transport Systems (ITS). The research focuses on designing and implementing a VLC-based V2V system for transmitting hard brake warnings from a leading vehicle to the following vehicle, with the aim of enhancing road safety.

The VLC-based V2V system is designed, utilizing the directionality property of VLC to enable efficient and secure communication between vehicles. Encryption techniques are employed to ensure data security and privacy. The system operates in a half-duplex mode, and experimental results demonstrate its effectiveness in transmitting hard brake warnings. The system achieves an average data packet delivery ratio of 95% and a delay of less than 50 milliseconds.

The paper addresses data security in light-based military ad hoc networks, proposing a protocol that leverages VLC's directionality to establish secure communication channels. The protocol employs Fractionated Ciphering, ensuring the transmitted data packets cannot be decoded by adversaries. Experimental evaluation shows that the protocol successfully mitigates unauthorized access and eavesdropping attempts.

Experiments are conducted to evaluate the performance of the VLC-based V2V system and the proposed security protocol in outdoor scenarios. Varying the inter-vehicular distance and data size, the system achieves a reliable communication range of up to 100 meters. The system demonstrates a high level of security, with no successful interception or decoding of transmitted data packets observed during the experiments.

In conclusion, the research validates the practical application of VLC in V2V communication for hard brake warnings, significantly enhancing road safety. The proposed security protocol effectively protects the confidentiality and privacy of data in light-based military ad hoc networks. The experimental results indicate a data packet delivery ratio of 95%, minimal delay, and a reliable communication range of 100 meters

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